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USAAVLABS TECHNICAL REPORT 67-16

FLOOR ACCELERATIONS AND PASSENGER INJURIES IN TRANSPORT AIRCRAFT ACCIDENTS

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May 1967

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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AVIATION SAFETY ENGINEERING AND RESEARCH
A DIVISION OF
FLIGHT SAFETY FOUNDATION, INC.
PHOENIX, ARIZONA

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DEPARTMENT OF THE ARMY
U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA 23604

This report has been prepared by the Aviation Safety Engineering and Research Division of the Flight Safety Foundation under the terms of Contract DA 44-177-AMC-360(T). It consists of a study to establish as closely as possible the crash environment for potentially survivable accidents.

This study discloses data pertaining to various G levels which occur in survivable accidents and also presents statistics on the number of fatalities involved in survivable-type accidents.

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SUMMARY

Floor level deceleration data obtained in FAA crash tests of a DC-7 and an L-1649 transport are analyzed and compared with earlier NACA data on twin-engine transports. Generally, the comparison of the NACA and FAA data revealed that for equal impact angles and velocities, the deceleration pulses as recorded by NACA and the FAA were nearly equal. When fuselage breaks occur, deceleration values in the separated sections may exceed the deceleration level of an intact airframe. The longitudinal compressive strength of a separated fuselage section may allow as much as 19G to be imposed on the section when one-third of the cross-sectional area is effective in buckling.

A study of 61 survivable transport aircraft accidents in the years from 1955 through 1964 revealed the following significant points.

1. Floor deceleration pulse magnitudes and durations seldom exceed human tolerance limits if proper body restraint is available.

2. At least one fuselage fracture "break" was noted in each of 35 accidents out of a total of 61 accidents studied, and these breaks resulted in seat failures and passenger injuries in many of these cases.

3. Two-thirds of the accidents studied resulted in a postcrash fire.

4. It is estimated that approximately one-half of the injuries and fatalities could have been prevented by the use of improved passenger restraint systems.

FOREWORD

The work described in this report was conducted by the Aviation Safety Engineering and Research (AvSER) division of the Flight Safety Foundation, Inc., under the provision of Contract DA 44-177-AMC-360(T) with the U. S. Army Aviation Materiel Laboratories. Funds for this study were provided in equal amounts by the National Aeronautics and Space Administration, the U. S. Army, the U. S. Navy, and the U. S. Air Force. The study was guided and monitored by Mr. I. Irving Pinkel and Mr. Jack Enders of NASA.

The authors extend grateful appreciation to the personnel of the accident records groups of the Civil Aeronautics Board, the Naval Aviation Safety Center, and the Air Force Safety Center for their assistance in selecting and providing the original accident investigation records. The work under this contract was begun in October 1964 and was completed in October 1966.

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ILLUSTRATIONS

INTRODUCTION

The objective of this study is to establish as closely as possible the crash environment for "potentially survivable accidents". Emphasis is placed on fixing the deceleration at the cabin and cockpit floor level and the velocity change in the primary impact pulse. To add significance to these results, an estimate of the "potential number of added survivors" which might have resulted from improved crashworthiness of seats is included.

APPROACH TO THE PROBLEM

The floor decelerations can be obtained by several methods:

1. Instrumented crash tests of full-scale and sub-scale components. (This method will yield the most accurate results.)

2. Theoretical analysis.

3. Estimates made from accident investigations.

The results of all three methods are used in this study.

EXPERIMENTAL CRASH TEST DATA

LONGITUDINAL FLOOR DECELERATIONS

Longitudinal floor deceleration levels in actual aircraft crashes vary with impact angle, impact velocity, terrain composition, and aircraft rigidity. The National Aeronautics and Space Administration (formerly National Advisory Committee for Aeronautics - NACA) has made a thorough evaluation of impact angle variation.[1,2] Crash tests were conducted on aircraft at pitch angles up to 50 degrees. The NACA data, as presented on page 64 of Reference 2, indicated that longitudinal decelerations varied from 5G at a 5-degree impact angle up to as high as 50G at impact angles above 45 degrees. The NACA data were recorded in light single-engine planes, in fighters, and in C-46 and C-82 transports at impact velocities up to 112 miles per hour.

The recently completed four-engine (Douglas DC-7 and Lockheed L-1649) transport crash tests conducted for the Federal Aviation Agency (FAA) by the Flight Safety Foundation indicate longitudinal floor decelerations about equal to those of the NACA tests for equal impact angles and impact velocities.[3,4]

Since the FAA crash tests of the DC-7 and L-1649 aircraft were conducted at several impact angles (6 degrees, 8 degrees, and 20 degrees), an analysis of this new data is included for comparison with the earlier NACA data. The DC-7 and L-1649 transport velocity-time and distance-time calculations, made from tests described in References 3 and 4, are presented in Figures 1, 2, and 3. The L-1649 velocity and distance-versus-time data for the entire impact sequence are shown in Figures 1 and 2. These curves show the major velocity changes which occur on the 6-degree and 20-degree slopes. Note that the maximum slopes of the velocity-time curve occur at about 1.05 and 3.2 seconds, respectively. Both slopes indicate an average deceleration of about 5G. This 5G value is based upon the center-of-gravity movement of the airplane as determined by high-speed ground camera analysis. The L-1649 floor-mounted accelerometers along the fuselage centerline (see Figure 4) indicate that the maximum deceleration values vary from 7G to 20G, as shown in Figure 5. Only the major decelerative pulses in the 6-degree and 20-degree impacts are recorded in Figure 5.

It will be noted in Figure 5 that the times plotted are 0.10 second less than the times shown for the same data in Reference 3. This difference results from the selection of main landing gear impact as time zero, as noted in Figures 5 and 6. Reference 3 uses propeller impact as time zero.

Several observations are pertinent in comparing the longitudinal G levels of the L-1649 airplane with those of the NACA transport tests:

6-Degree Impact (L-1649)

1. The maximum G level recorded in the 6-degree impact varied from about 11G in the nose to about 8G in the rear of the cabin, if the short duration (0.010 second or less) spikes are ignored. These G levels are significantly higher than the 2.5G recorded in the C-46, 5-degree (119 feet per second) NACA test.

2. The maximum deceleration in the L-1649 test was about four times as great as that for the C-46; however, the pulse duration was shorter. The velocity changes for the two aircraft at equal impact angles were about the same.

3. The time at which maximum decelerations were reached varied by about 0.015 second between the nose and rear section of the cabin; i. e., the rear section peak G lagged the nose section by 0.015 second.* This same trend was also noted in the NACA C-46 tests at 15- and 29-degree impact angles.

20-Degree Impact (L-1649)

1. The maximum G level recorded in the 20-degree impact varied from 19G in the nose to about 8G at the four locations aft of the nose. All the evidence indicates that this difference was caused by a buckling collapse of the cabin section at the forward break location shown in Figure 4. The entire nose section was pushed upward about 3 to 4 feet relative to the aft fuselage section. The structure in the vicinity of this fuselage then provided a "plastic" connection between the forward and aft fuselage, allowing a low-level deceleration of the aft section. Had the aircraft impacted on a greater slope, or at a higher velocity, the remainder of the cabin undoubtedly would have experienced a higher deceleration than was recorded in this case. It is concluded that the nose section provided enough energy absorption in this impact to prevent the aft fuselage G levels from exceeding those recorded in the 6-degree impact.

* The longitudinal time base as recorded in Figure 6-3 of Reference 4 is in error by 0.075 second. All times are 0.075 second higher than they should be at fuselage station 460.

2. The time at which maximum G levels were reached varied about 0.25 second between the nose section and the other locations. This difference was caused by the collapse of the structure at fuselage station 350, which allowed the aircraft to move forward some 20 to 22 feet before the center fuselage body at the "break" point made full contact with the 20-degree slope, as illustrated in Figure 4. The center and aft fuselage reached its maximum deceleration at this time. This test indicates clearly that the several sections of a passenger cabin may be decelerated at different levels if the cabin structure breaks up during the crash sequence.

The longitudinal decelerations at the floor level in the DC-7 transport crash test were obtained in the cockpit area only. A review of the velocity-time curves in Figure 3 indicates an average 8-9G deceleration in the 8- and 20-degree impacts. It will be noted in Figures 3 and 7 that the times plotted are 0.10 second less than the times shown for the same data in Reference 4. The main landing gear impact was chosen for time zero in this study.

The longitudinal deceleration-time trace for the cockpit is shown in Figure 7 for the 8-degree and 20-degree impacts. Maximum decelerations of 15G and 28G are shown, respectively, for the two impacts. A review of these data permits the following observations and conclusions:

8-Degree Impact (DC-7)

1. The 15G maximum cockpit reading is approximately 50 percent greater than that of the L-1649 transport for a 6-degree impact. The larger initial impact velocity of 235 feet per second rather than 185 feet per second was undoubtedly a contributing factor to the higher G level.

2. Although the forward fuselage did fracture at a point about 400 inches aft of the nose (fuselage station 300) during the impact, all evidence indicates that the fracture was initiated by a propeller blade slash through the right side at that station. It is possible that the fuselage would have remained intact during this impact if the propeller blade had not penetrated the structure.

20-Degree Impact (DC-7)

The maximum G level in the cockpit was about 28G, as shown by the averaged trace in Figure 7. The inward crushing of the cockpit was severe enough to preclude survival of the pilot and copilot; however, the passenger compartment forward of the fuselage break point was not crushed extensively in the 20-degree impact and was thus a potentially survivable area.

VERTICAL FLOOR DECELERATIONS

The vertical floor decelerations for the L-1649 and DC-7 transports are shown in Figures 6 and 7, respectively. The vertical deceleration-time traces at stations 923 and 1165 for the L-1649 aircraft are not included in Figure 6 because the levels were much lower than those in the forward fuselage. It can be seen that the peak G values in the L-1649 cockpit are about 20 and 30G, respectively, for the 6-degree and 20-degree impacts, while the fuselage station 685 (c. g.) deceleration is relatively low at about 7G maximum. This large difference is to be expected in nose-low impacts because of the rapid vertical velocity change which must occur at the nose when contact is made. The velocity changes in the cockpit were about 35 and 55 feet per second, respectively, for the L-1649 and DC-7 in the 6-degree and 8-degree impacts.

LATERAL FLOOR DECELERATIONS

Neither the L-1649 nor the DC-7 crash tests were intended to produce significant lateral forces. Minor lateral forces up to about 9G peaks were noted in both aircraft after the nose section breaks occurred; however, the duration of these decelerations did not exceed 0.03 second.

COMBINED FLOOR DECELERATIONS

The L-1649 and DC-7 data indicated that the maximum decelerations occurred along the three axes simultaneously.

DECELERATION PULSE SHAPES

A review of the NACA and FAA longitudinal, vertical, and lateral pulse data indicates that a symmetrical, triangular shape will simulate the measured pulses in the majority of the tests. Until more data are gathered on various aircraft types, it appears feasible to use this pulse shape for aircraft seat testing.

INITIAL IMPACT VELOCITY EFFECTS

Less experimental data are available on the effect of impact velocity than are available on impact angle. The majority of the NACA aircraft were impacted at velocities between 80 and 112 miles per hour, while the L-1649 and DC-7 tests were conducted at 129 and 160 miles per hour, respectively. In an effort to determine the effect of impact velocity on longitudinal floor deceleration at equal impact angles, the applicable data from the NACA and FAA tests are compared as shown by the curve in Figure 8. This figure shows that the initial impact velocity varied between 80 and 160 miles per hour. All of the aircraft were impacted on compressed soil without obstructions. An increasing longitudinal G value with increasing impact velocity is indicated, although the curve appears to be leveling off at the higher velocities. Aircraft weight appears to have little effect on longitudinal G level.

MISCELLANEOUS EFFECTS

Aircraft rigidity, as used in regard to longitudinal floor deceleration, is a measure of the aircraft's resistance to deformation. The more rigid aircraft structure should offer greater resistance to deformation and for equal weight should be expected to yield a higher G level than a less rigid structure. An insufficient number of crash tests have been conducted to evaluate this factor experimentally. Theoretical calculations to determine the longitudinal resistance to deformation (crushing strength) of several transport fuselages are discussed in the next section.

The type of terrain onto which an aircraft impacts will probably affect deceleration levels; however, little experimental data on the effect of terrain are available. All of the NACA crashes were conducted on prepared soil. No instrumented tests have been conducted to determine the effect of impacts onto water, sand, rocks, trees, or pavement. Soft-soil impacts probably yield higher decelerations due to the "plowing" action. Some preliminary results have been obtained on the effects of "plowing" for a small, twin-engine (20-ton) aircraft.[5] Further work in this area should yield more precise data for larger aircraft.

THEORETICAL ANALYSIS

INTRODUCTION

Only limited experimental data are available on the floor level decelerations for large, modern, transport aircraft. This theoretical analysis is presented to fix the probable limits of the fuselage to deceleration as determined by the fuselage buckling loads.

It is assumed that only about 1/4 to 1/3 of the fuselage shell cross-sectional area would ever be greatly compressed other than in very steep angle impacts. Only the skin and longerons below the floor line were thus assumed to be effective in compression. The compression strength of the floor was not considered. A transport powered by four jet engines and a transport powered by four piston engines were analyzed.

FUSELAGE CROSS-SECTIONAL ANALYSIS

The fuselage cross section used for the analysis was located just aft of the wing-to-fuselage intersection for both aircraft; however, the exact location is relatively unimportant, since the total area of the skin and longerons does not vary greatly in the constant-geometry section of the fuselage. Figure 9 illustrates a DC-7 tail section being decelerated as assumed in this analysis.

The resultant deceleration levels for a tail section loaded with a half load and a full load of passengers and baggage are presented in Table I.

TABLE I
FUSELAGE STATIC COMPRESSIVE STRENGTH FOR LOWER ONE-THIRD OF SHELL

	Four-Engine Piston Transport	Four-Engine Jet Transport
Compression Capacity, lb	350,000	432,000
Resultant Deceleration (Half Passenger Load), G	19	15
Resultant Deceleration (Full Passenger Load), G	16	13

At least three survivable accidents have occurred to a four-engine piston transport whose fuselage cross-sectional geometry was identical to that of the piston transport analyzed above. It is interesting to note that the tail section broke free from the forward fuselage at a corresponding location (the same distance forward from the rear pressure bulkhead) in all three accidents. About half of the passengers in the torn-free tail sections of the three transports survived. It is concluded, therefore, that fuselage breaks in aircraft crashes need not be catastrophic if passengers are properly restrained in the separated sections.

A similar compressive strength analysis was conducted by the Convair Division of General Dynamics Corporation for the Federal Aviation Agency on a twin-engine transport and a four-engine jet. In this analysis, the lower half of the fuselage was assumed to be effective rather than just the area below the floor level. The Convair results are included in Table II for comparison purposes.[6]

TABLE II
FUSELAGE COMPRESSIVE STRENGTH FOR
LOWER ONE-HALF OF SHELL

	Twin-Engine Piston Transport	Four-Engine Jet Transport
Compression Capacity, lb	251,000	670,000
Resultant Deceleration (Half Passenger Load), G	28	29
Resultant Deceleration (Full Passenger Load), G	21	21.5

It can be seen that the Convair G values are about 50 percent greater than those shown in Table I, but this is to be expected since one-half of the fuselage cross section was assumed to be effective rather than about one-third. It is significant that the structural G limits as calculated for aircraft varying in gross weight from 45,000 pounds for the twin-engine transport up to 300,000 pounds for the four-engine jet do not vary greatly.

The tail section need not break away from the forward fuselage, as illustrated in Figure 9, for it to be subjected to its structural deceleration limits. In steep-angle impacts (15 degrees or greater) with modern long-nosed aircraft, it appears probable that the forward fuselage will break at the wing intersection and thus permit the center section fuselage to dig in and "plow". The plowing, of course, could cause structural limit decelerations on the remainder of the fuselage.

ESTIMATES OF CRASH FORCES AND PASSENGER SURVIVAL POTENTIAL FROM ACCIDENT STUDIES

BACKGROUND

Although estimates of crash forces and injury causation factors are very difficult to obtain from accident histories, a careful study of competent investigators' notes on a sizeable number of accidents can yield useful trend information where the study considers existing test data as a "yardstick" for the derived estimates. For transport aircraft, "yardstick" test data have been obtained by the NACA and FAA on piston-powered, pressurized aircraft up to a gross weight of 80 tons at several impact angles up to 29 degrees.[1, 2, 3, 4] Since the majority of survivable accidents have occurred in piston-powered transports, the available accident history information is generally comparable with the test data.

Crash forces can also be estimated on the basis of failure or nonfailure of passenger restraint systems (seats and associated attachment fittings) which are designed to specified static strength levels, because it is known that the dynamic strength of materials is about the same as the static strength for the loading rates experienced in aircraft accidents. For example, in the FAA crash test of the L-1649 transport,[4] the peak longitudinal floor deceleration was 10-15G in the forward part of the cabin, and the standard commercial 16G-static-strength seats did not fail in the test.* Thus, a postcrash analysis of this accident would have suggested that the seats sustained a longitudinal force of less than 16G.

The statistical information presented herein has been obtained by a study of transport aircraft accidents with particular emphasis on crash forces, passenger injuries, and the number of injuries which might have been prevented by the use of improved occupant restraint systems.

*Although these seats were required to withstand only a 9G static loading with floor fittings capable of sustaining 12G in accordance with FAA Technical Standard Order No. 39, the actual failure load determined by static tests was about 16G for the triple passenger seats with 170-pound passengers.

TYPES OF ACCIDENTS STUDIED

Aircraft accidents can be logically grouped into three classes as follows:

1. Minor impact forces - These include taxiing collisions, landing gear failures after touchdown, or any other impacts in which the decelerative forces on the occupants do not exceed about 4G.

2. Moderate to severe impact forces - These include accidents in which the aircraft strikes terrain at approach/landing speeds in which the decelerative forces are in excess of 4G but are not greater than human tolerance levels.

3. Catastrophic impact forces - These include accidents in which the aircraft's vertical velocity is excessive (100 feet per second or more) or in which G forces are in excess of human tolerance.

Accidents falling under class (2) were selected for this study. Contact was made with the Civil Aeronautics Board and the military safety centers to obtain permission to review original accident investigation notes, photographs, and other data not normally included in formal accident reports. Class (2) accident cases were selected for study from the above sources after a review of all accidents. Only accidents meeting the following limitations were used in the study:

1. Aircraft weight was greater than 10 tons.

2. Aircraft was multi-engined.

3. At least one person was injured in the accident to the extent that he was (a) hospitalized for 24 hours and/or (b) received bone fractures, excluding toes, fingers, and nose.

4. At least one person did survive the accident, or at least conclusive evidence indicated that survival would have been possible if proper body restraint had been used. The fact that the fuselage structure was not crushed to the extent to preclude survival was taken as one indication that survival should have been possible. The severity of the accident, including estimated velocity change, impact angle and estimated G levels, provided further evidence of survival potential.

ACCIDENT DATA COLLECTION PROCEDURE

In order for the study to be statistically significant, a 10-year span for the years 1955 through 1964 was selected for accidents investigated by the Civil Aeronautics Board. The military accidents were selected for the years 1962 through 1965 because the older case histories were not readily available.

Detailed work sheets were prepared for use with each accident case, and a visit was made to the Naval Aviation Safety Center at Norfolk, Virginia, and the U. S. Air Force Safety Center at Norton Air Force Base, California, as well as the CAB in Washington, D. C., so that a detailed review of photographs, wreckage distribution charts, original notes, and other data could be conducted. A portion of the original data collected is summarized in Appendixes I and II for the civil and military transports, respectively. Note that a total of 61 aircraft are included in this study. These tables are self-explanatory and provide an estimate of the following:

1. Type of aircraft.
2. Aircraft attitude at time of major ground impact.
3. Aircraft velocity at major ground impact.
4. Impact angle (angle between flight path and terrain slope).
5. Total deceleration distance (distance moved after first terrain contact).
6. Total persons aboard.
7. Crew injuries.
8. Passenger injuries.
9. Occurrence of postcrash fire.
10. Terrain condition.

It must be realized that the kinematic data presented are not exact in some cases, but an effort has been made to bracket the correct value by indicating upper and lower limits. For propeller-driven aircraft, the distance between prop marks in the terrain is matched to engine power settings to reveal a good estimate of initial impact velocity. For jets, the flight recorder indicates flight speed, sink rate, and the initial vertical G level upon impact.

The accident cases listed in Appendixes I and II were further studied in order to estimate the crash forces during the major pulses. This was done by comparing each accident case with an equivalent aircraft which had been crash tested under similar conditions. All four-engine aircraft were thus compared with the FAA crash tests of the L-1649 and DC-7,[3,4] while all twin-engine aircraft were compared with either the NACA Lodestar, C-46, or C-82 transport crash tests. Consideration was also given to the failure or nonfailure of passenger seats in estimating the average G values. The estimated velocity changes and average G levels are presented in Tables III, IV, V, VI and VII.

The velocity and crash force data in the tables are further reduced and presented statistically in Figures 10 through 14. These curves enable the reader to determine the crash forces and velocity changes in survivable accidents on the basis of probability.

DISCUSSION OF CRASH KINEMATICS AND KINETICS

A review of the data in Tables III through VII and Figures 10 through 14 reveals the following pertinent points:

1. There is a large difference between the average (50th percentile) impact conditions and the 95th percentile conditions.

2. It is probable that an average longitudinal deceleration of 13G or less will occur in 95 percent of all potentially survivable crashes.

3. It is probable that vertical G values of 18G average or less will occur in 95 percent of survivable accidents.

4. Lateral decelerations are not expected to exceed an average value of 8G in 95 percent of survivable accidents.

5. Horizontal velocity changes in the major impact pulses are not expected to exceed 64 feet per second in 95 percent of survivable crashes.

6. Vertical velocity changes are not expected to exceed 36 feet per second in 95 percent of survivable crashes.

7. The deceleration pulse magnitude and duration for the 95th percentile accident severity are not expected to exceed human tolerance limits longitudinally; however, some spinal column injuries may occur due to vertical pulses for the 95th percentile accident severity if energy-absorbing methods are not used in the seats.

8. A fuselage structural break occurred in at least one location in 35 accidents out of 61 (58 percent of the total). For impact angles greater than 10 degrees, 11 of the 16 accidents (68 percent) listed resulted in fuselage fractures. These facts suggest that more consideration should be given to the probability of fuselage fractures in survivable crashes.

PASSENGER INJURIES

The cases listed in Appendixes I and II were also studied to determine injury causes. This analysis was undertaken to be able to estimate the number of persons that might have survived the accident with only minor injuries. The number of potential survivors was determined for each accident on the basis of the following limitations:

1. Accidents with estimated floor longitudinal or vertical decelerations in excess of an average 25G were considered to be nonsurvivable because human tolerance limits with seat belt restraint only would probably have been exceeded.

2. Accidents in which excessive crushing of fuselage structure in occupiable areas occurred were considered to be nonsurvivable in those areas. For example, those cases in which seats were located over or near "break" points in the fuselage were considered to be nonsurvivable, regardless of seat failures.

The fatality and injury data are presented in Tables III, IV, V, VI and VII. These tables include the following:

1. Total persons aboard.

2. Total fatalities.

3. Total survivors.

4. Total survivors without serious injury.

5. Potential additional survivors without serious injuries.

The commercial transport cases were divided into impact angle increments between 0 and 5 degrees, 5 and 10 degrees, and 10 degrees or more, and the data are presented in Tables III, IV, and V, respectively. The same procedure was followed with the military cases except that the 5-to-10-degree range was omitted because of insufficient cases. The military accidents are listed in Tables VI and VII.

The "potential additional survivors" column in the tables shows the number of passenger and crew fatalities and seriously injured persons who probably could have survived with only minor injuries. In some cases, where insufficient injury information was available, a range of potential survivors was listed. In the majority of cases, fatalities and serious injuries were attributed either directly or indirectly to inadequate restraint. Fatalities were caused in several accidents by occupant inability to open jammed exits before postcrash fires consumed the fuselage (reference case 26); however, in this and similar cases, it was assumed that improved passenger restraint would not have prevented fatalities, and no possible survivors were added.

There are 3 accidents listed in Tables III, VI and VII in which the total fatalities due to fire are "unknown". A total of 23 fatalities occurred in these 3 accidents, some probably due to fire and some due to impact alone. It is possible that some of these passengers might have survived in the absence of fire, however, these are not shown in the "potential additional survivors" column.

Postcrash fires occurred in two-thirds of the 61 accidents reviewed, and fire caused 46 percent of all fatalities. In almost all cases, the cause of fire was a ruptured fuel tank due to wing failure. The primary effects of postcrash fires in civil transport accidents during the period of this study are reported in References 7 and 8.

STATISTICAL SUMMARY OF PASSENGER INJURIES

The following pertinent injury facts may be obtained by a review of Tables III through VII.

One thousand six hundred sixty-seven persons were on board the aircraft involved.

Two hundred ninety-six persons received serious injuries (18 percent of total).

Seven hundred forty-one persons were fatalities (44 percent of total). Three hundred forty of these were caused by fire while the remainder were caused by impact injuries.

Six hundred thirty persons received minor or no injuries (38 percent of total).

Somewhere between 340 and 520 additional persons could have survived the accidents without serious injuries (i. e., between 33 and 50 percent of the 1037 fatalities and seriously injured persons might have survived with minor or no injury if improved restraint systems had been used).

Thirty-three aircraft crashed at impact angles of 5 degrees or less (54 percent of total).

Twelve aircraft crashed at impact angles from 5-10 degrees (20 percent of total).

Sixteen aircraft crashed at impact angles greater than 10 degrees (26 percent of total).

Forty accidents resulted in postcrash fire (two-thirds of total).

CONCLUSIONS

It is concluded that:

1. The 95th percentile accident will result in a cockpit floor longitudinal deceleration pulse which is approximately a symmetrical triangle with a 25G peak and a velocity change of 64 feet per second. Cockpit seats should be designed to these values.

2. Cabin seats should be designed to at least 80 percent of the 95th percentile (cockpit) G level. This results in 20G at the floor. The 95th percentile longitudinal velocity change (64 feet per second) should be the same as in the cockpit area.

3. Seat failures in many accidents are caused by floor distortion at the leg-to-floor attachments rather than by excessive G loads. Improved leg-to-floor attachments would prevent many of the seat failures.

4. A study of 61 survivable aircraft crashes indicated that nearly half of the 1037 fatalities and serious injuries which occurred could probably have been prevented by the use of improved restraint systems. Reduction of postcrash fires would reduce the fatality and injury rate still further.

5. Fuselage fracture "break" points, which occurred in 35 of the 61 accidents studied, result in injuries and fatalities when passenger seats are located over these points.

RECOMMENDATIONS

It is recommended that:

1. Crash force studies of actual aircraft accidents be continued. Dynamicists working alongside CAB and military accident investigation teams could gain invaluable crashworthiness information in selected accidents.

2. Consideration be given to locating passenger seats away from expected fuselage "break" or fracture points so that the passenger's restraint system remains intact when fracture of the fuselage occurs.

3. Provision be made for relative rotation of the seat legs with respect to the aircraft floor.

4. Cockpit seats be designed to the 95th percentile conditions presented in Figures 10 through 14 of this report.

5. Cabin seats be designed to the 95th percentile velocity change (64 feet per second) and at least 80 percent (20G longitudinal) of the 95th percentile deceleration.

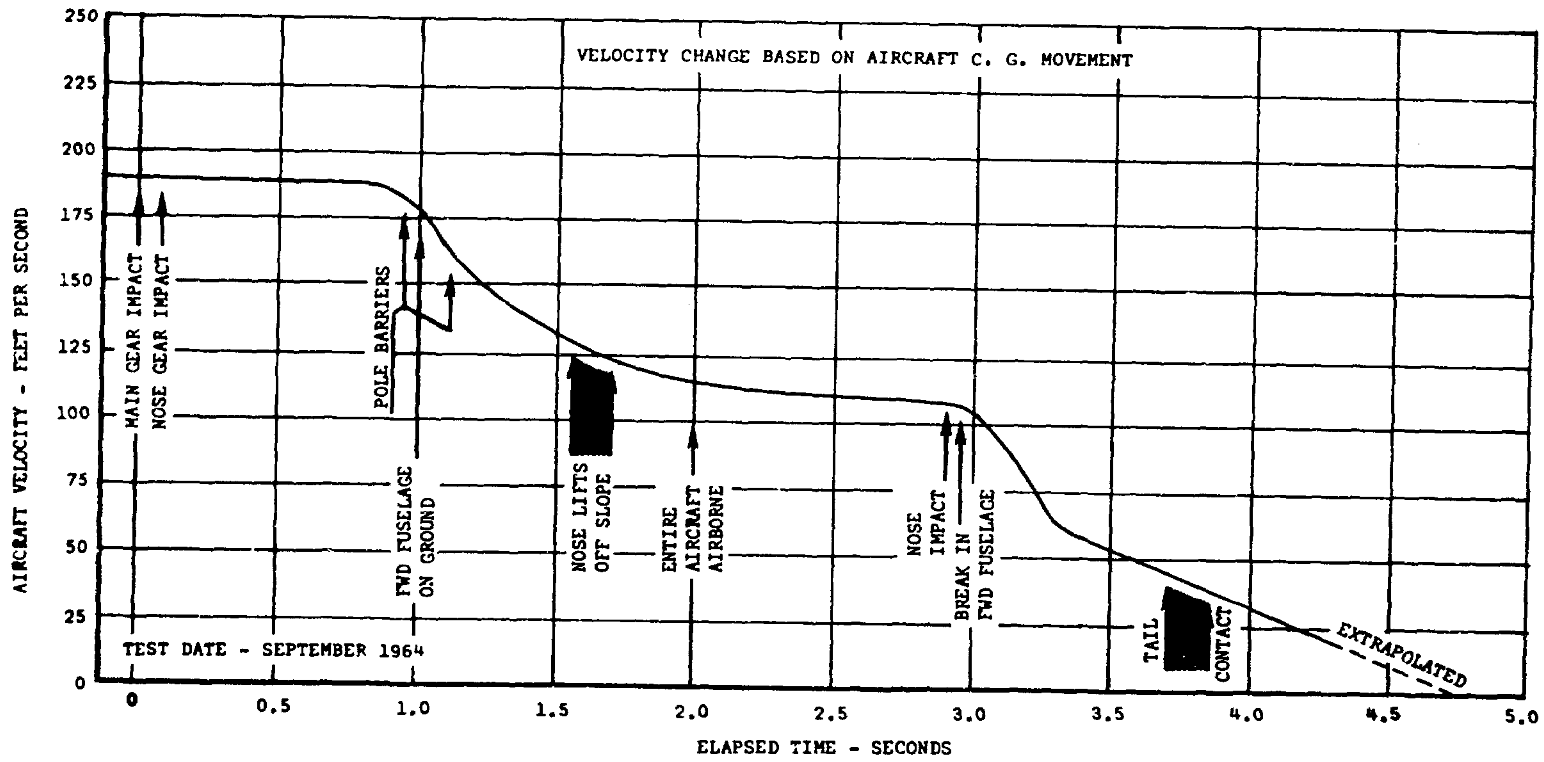

Figure 1. L-1649 Crash Test Velocity-Time History.

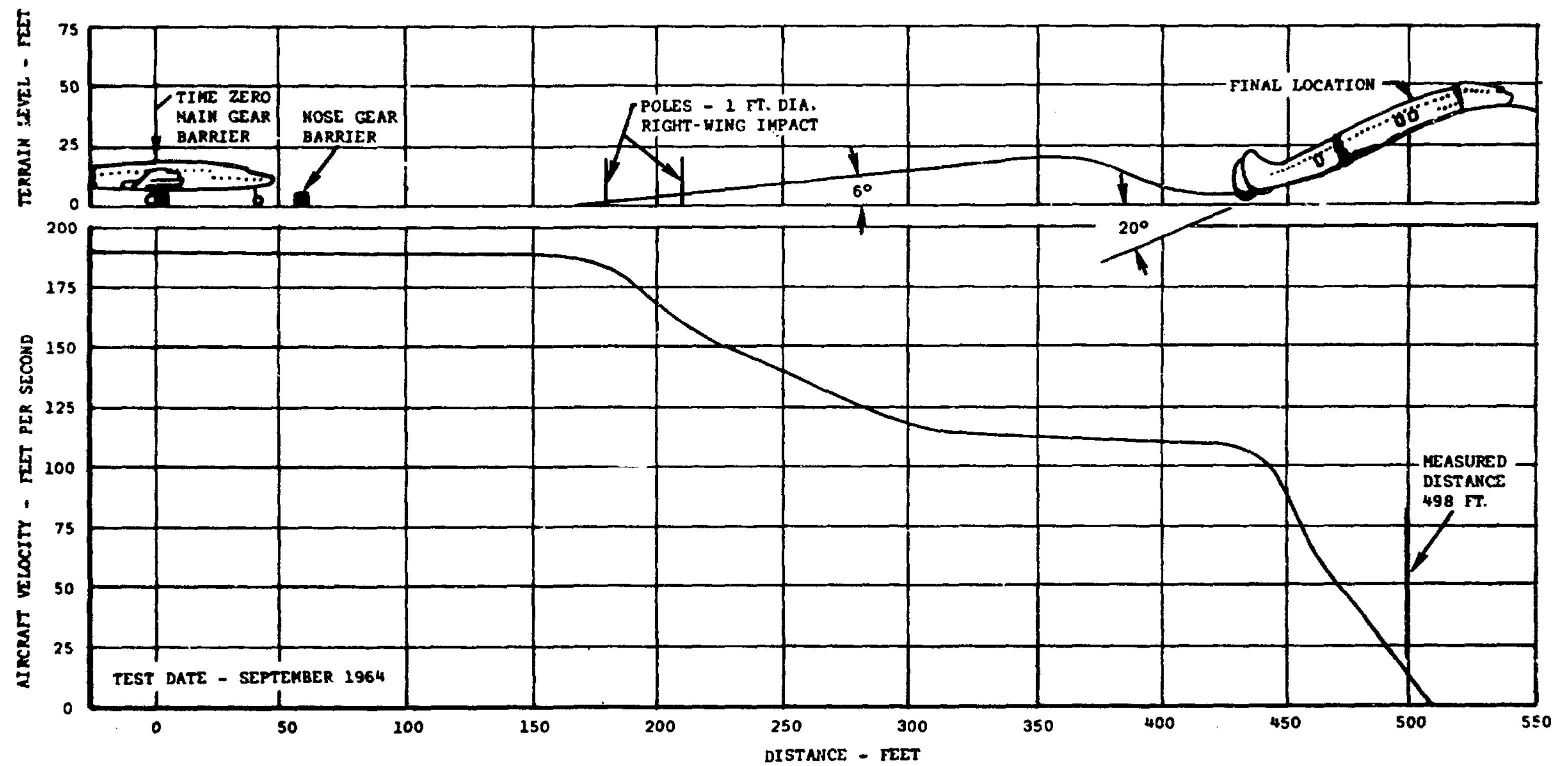

Figure 2. L-1649 Crash Test Velocity-Distance History.

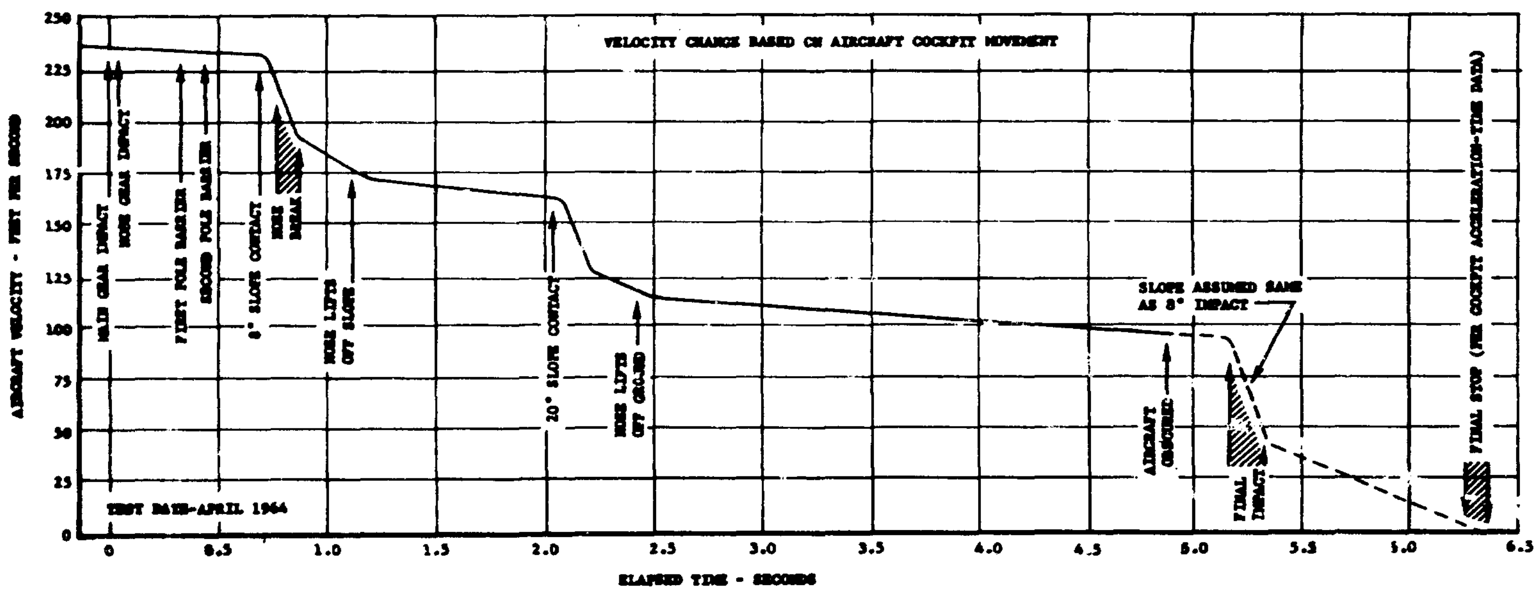

Figure 3. DC-7 Transport Crash Test Velocity-Time History.

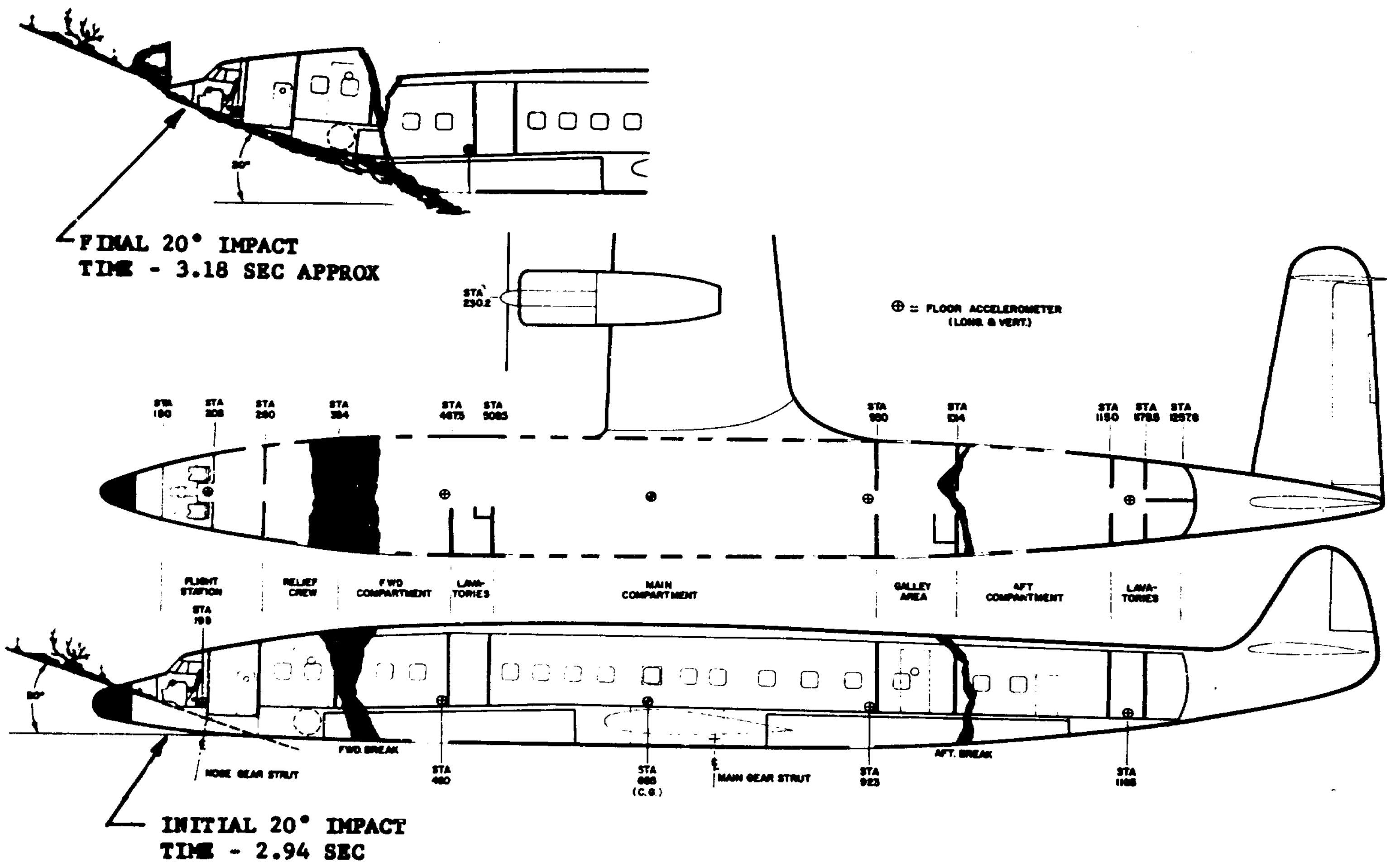

Figure 4. Location of Floor Level Accelerometers for X, Y and Z Recordings.

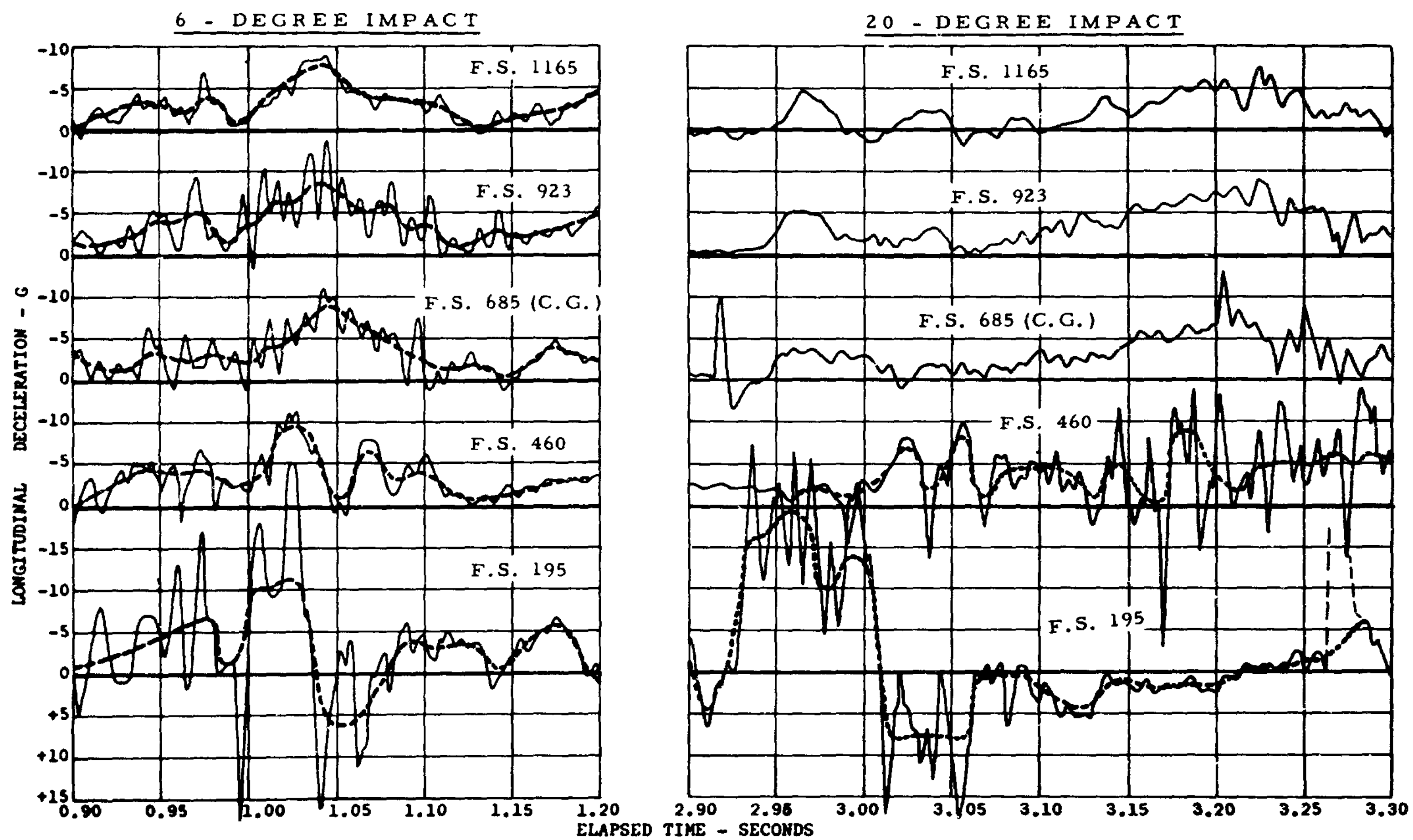

Figure 5. Longitudinal G Values for a 6-Degree and 20-Degree Impact - Lockheed L-1649 Transport.

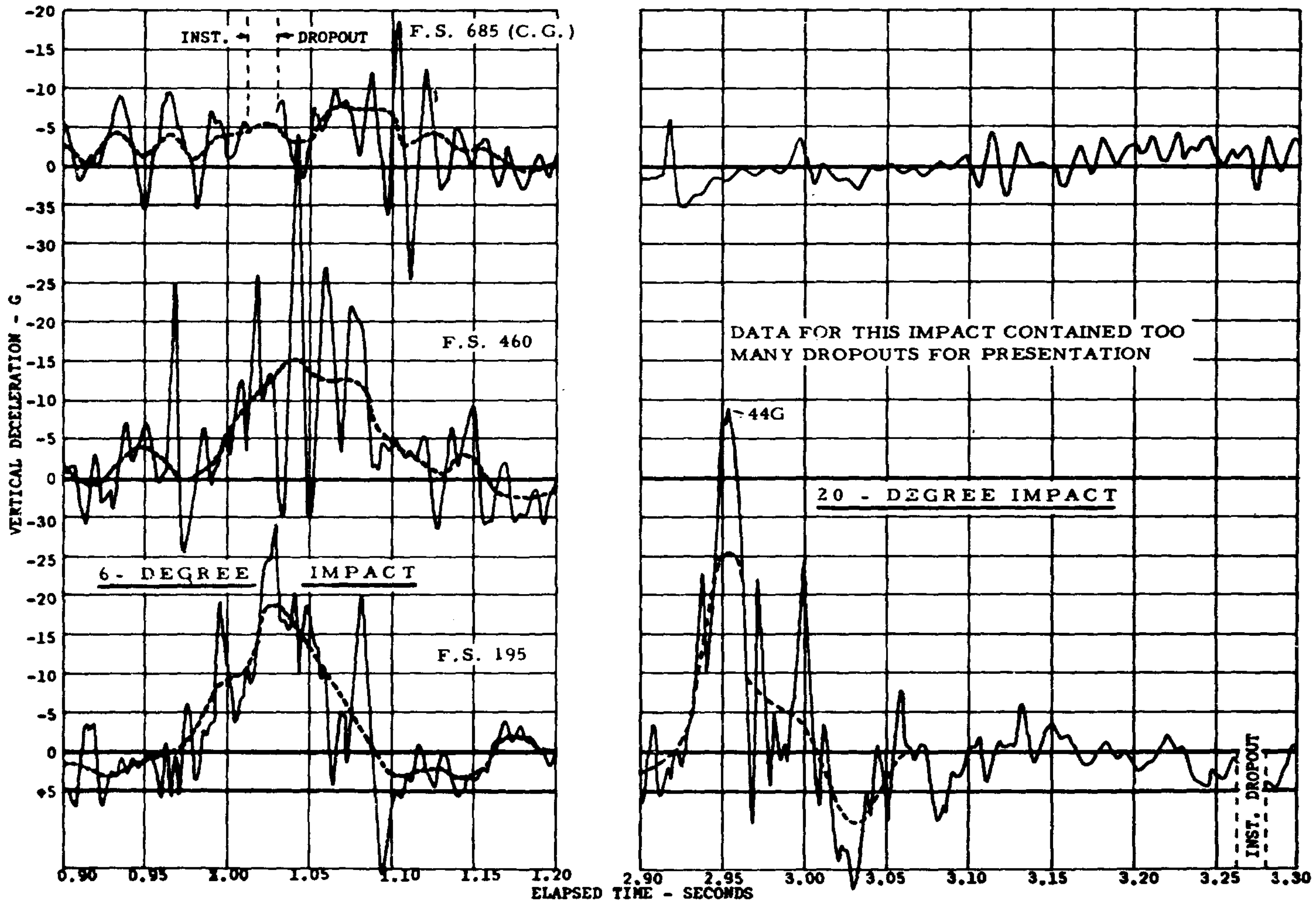

Figure 6. Vertical G Values in a 6-Degree and 20-Degree Impact - Lockheed L-1649 Transport.

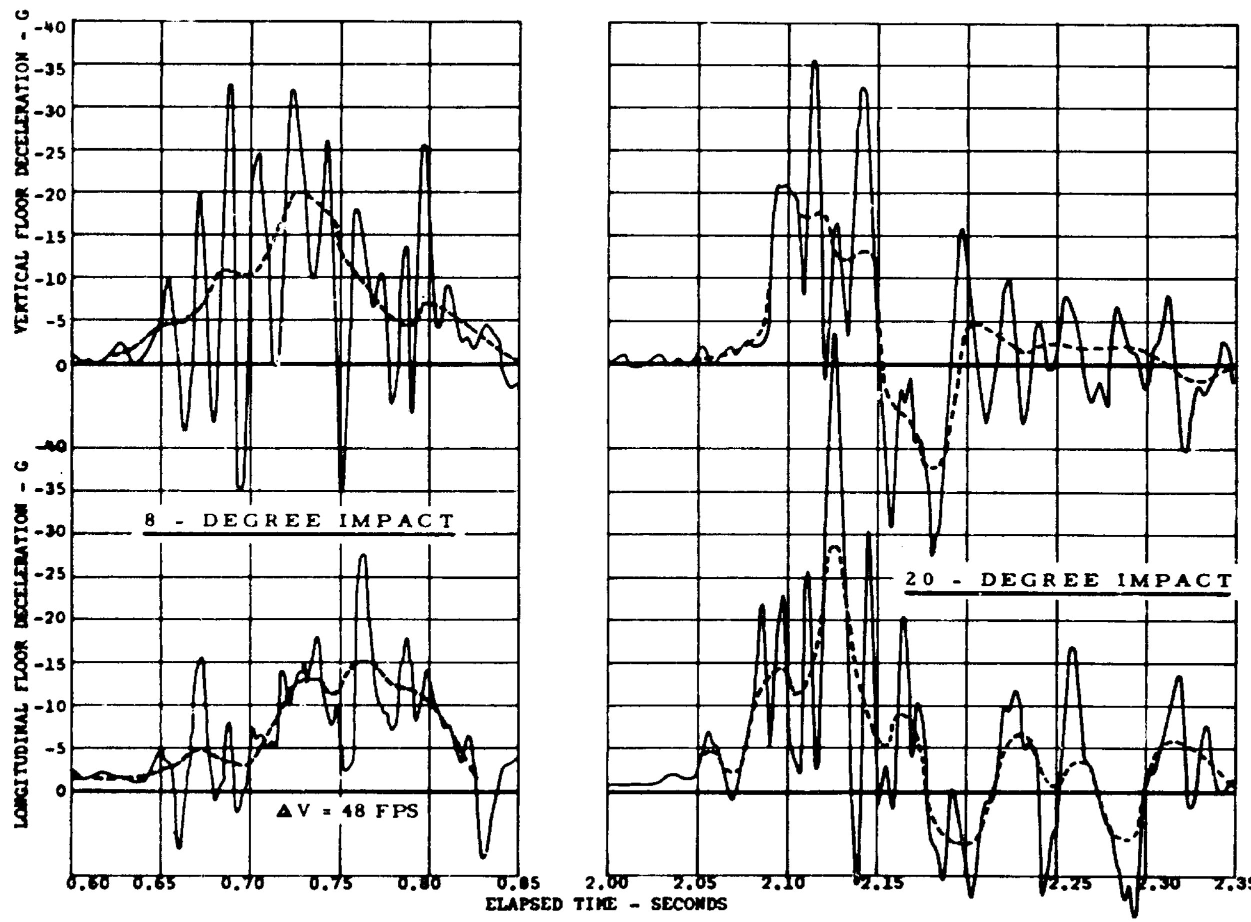

Figure 7. Longitudinal and Vertical G Values in an 8-Degree and 20-Degree Impact - Douglas DC-7 Transport.

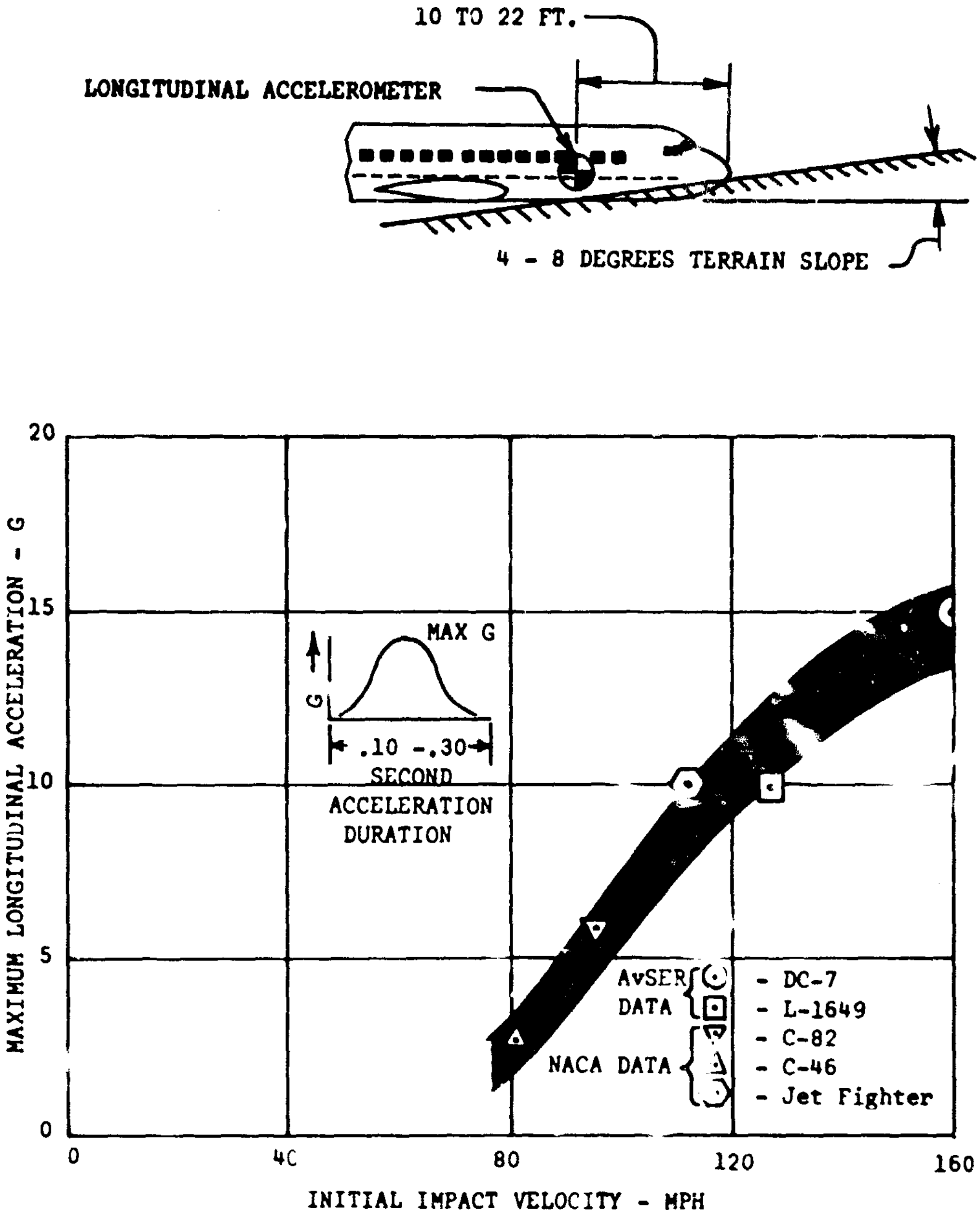

Figure 8. Forward Fuselage Longitudinal Acceleration Measurements in Low Angle Impacts.

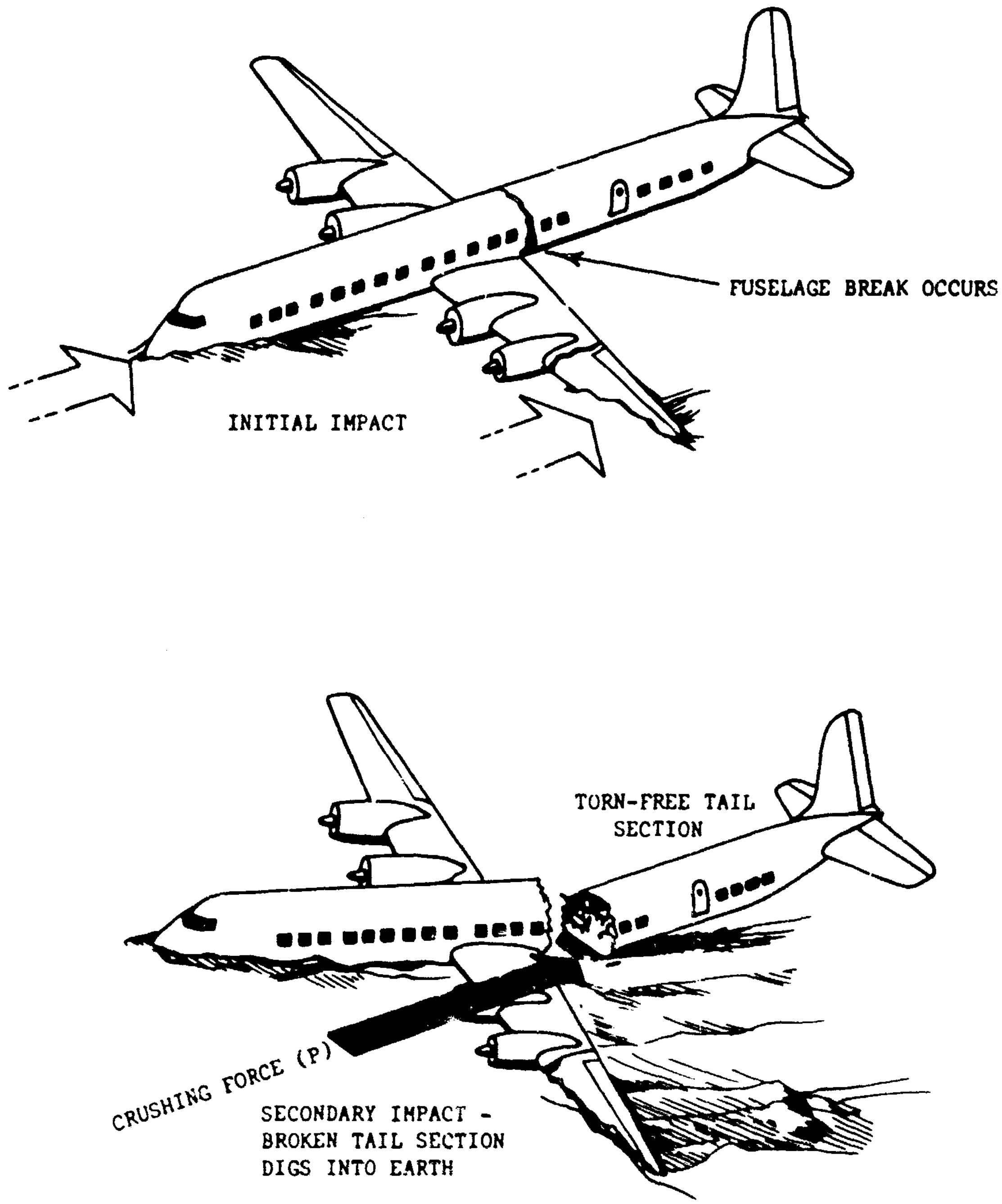

Figure 9. Illustration of a Broken Tail Section "Digging In" as Aircraft Breaks Up. (The tail section broke at the indicated location on this type of aircraft in at least three actual survivable crashes.)

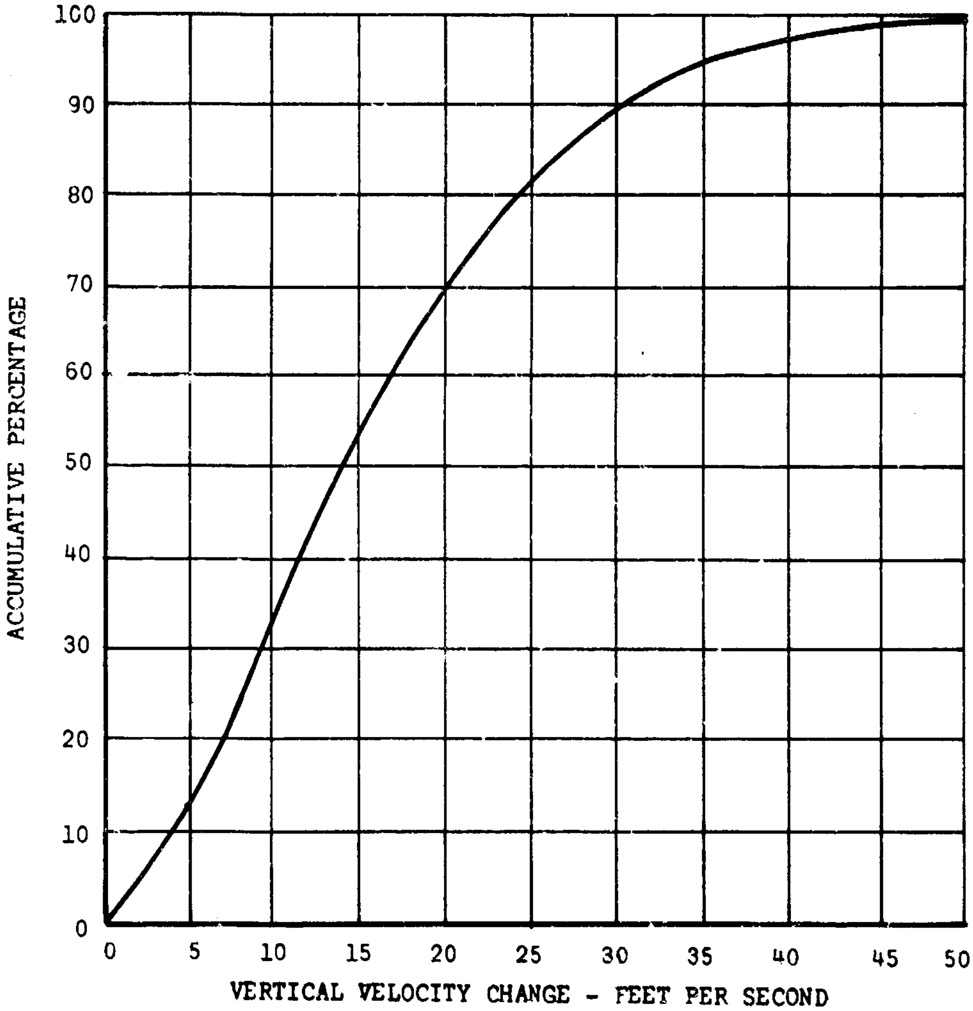

Figure 10. Distribution of Vertical Velocity Changes - Fixed-Wing Transport Aircraft.

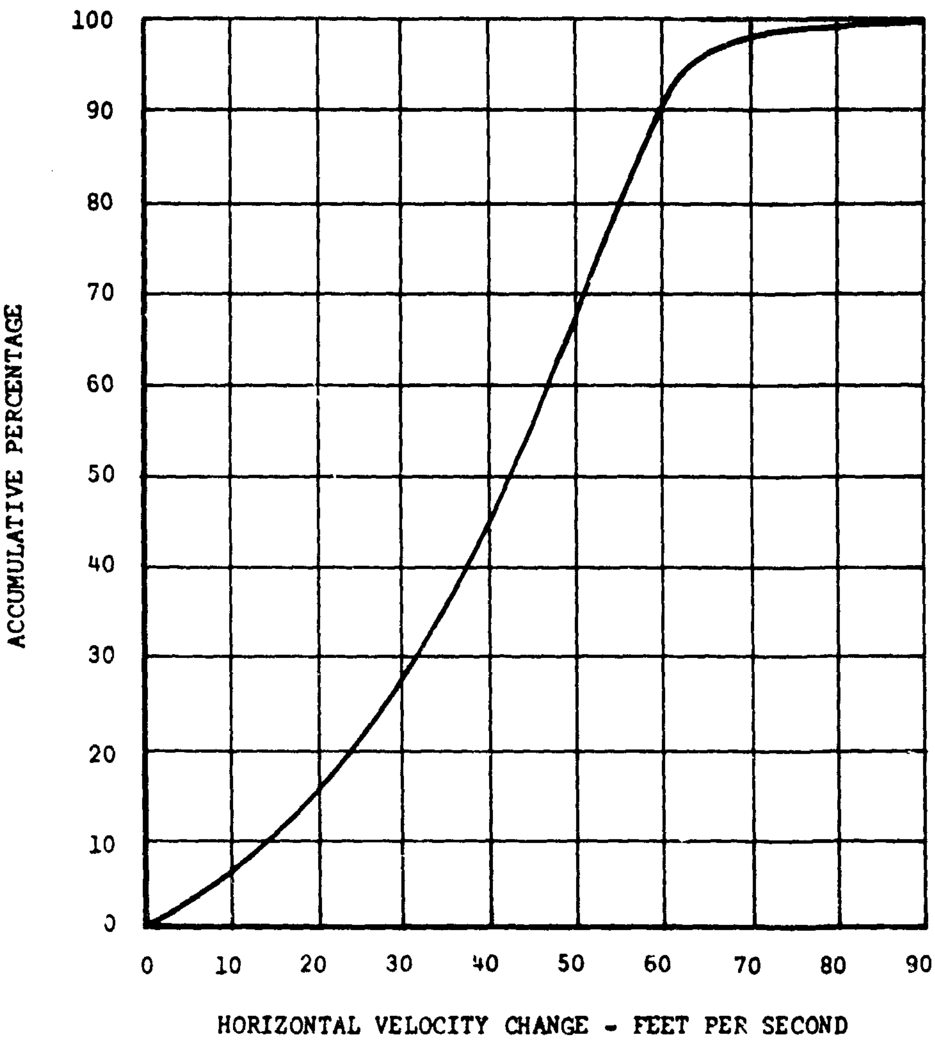

Figure 11. Distribution of Longitudinal Velocity Changes - Fixed-Wing Transport Aircraft.

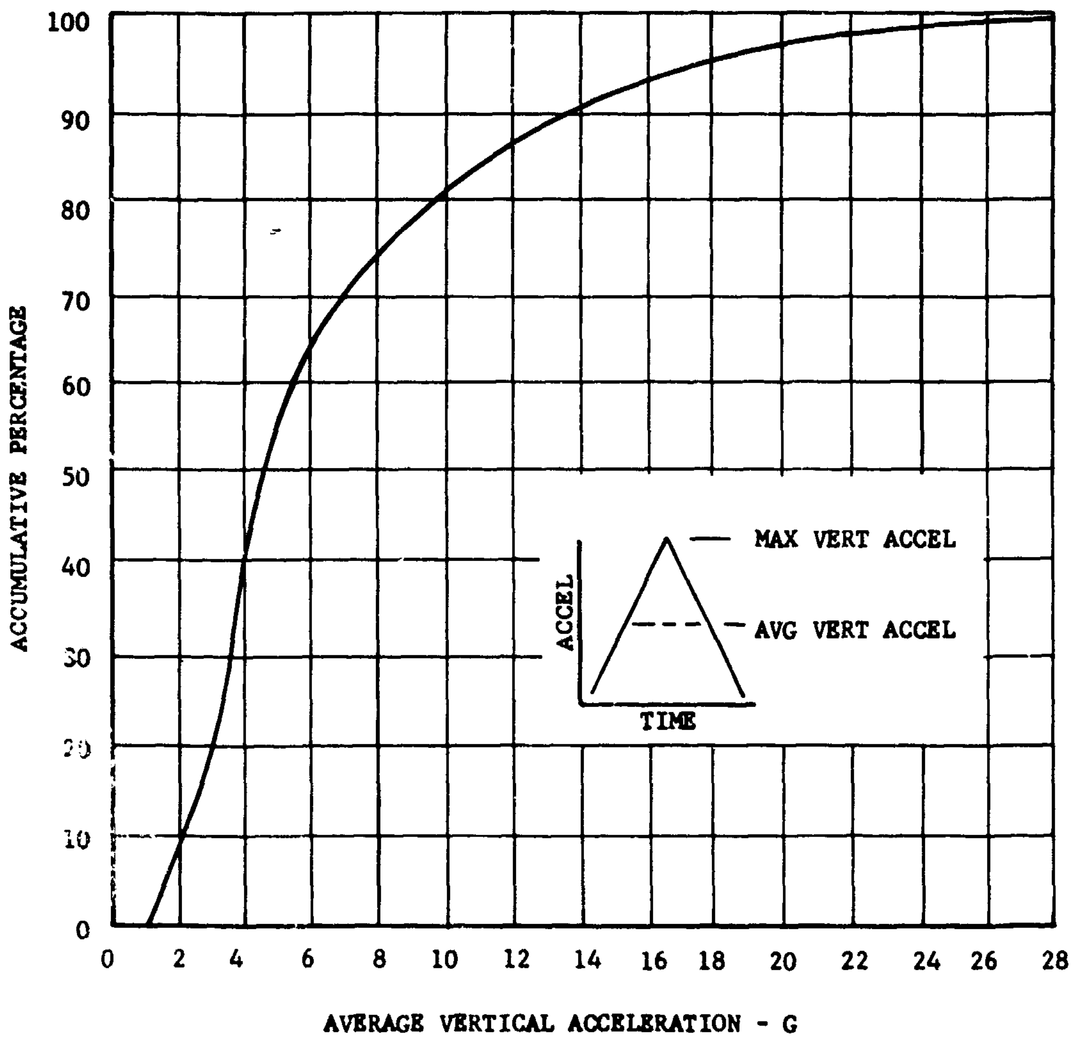

Figure 12. Distribution of Vertical Impact Forces - Fixed-Wing Transport Aircraft.

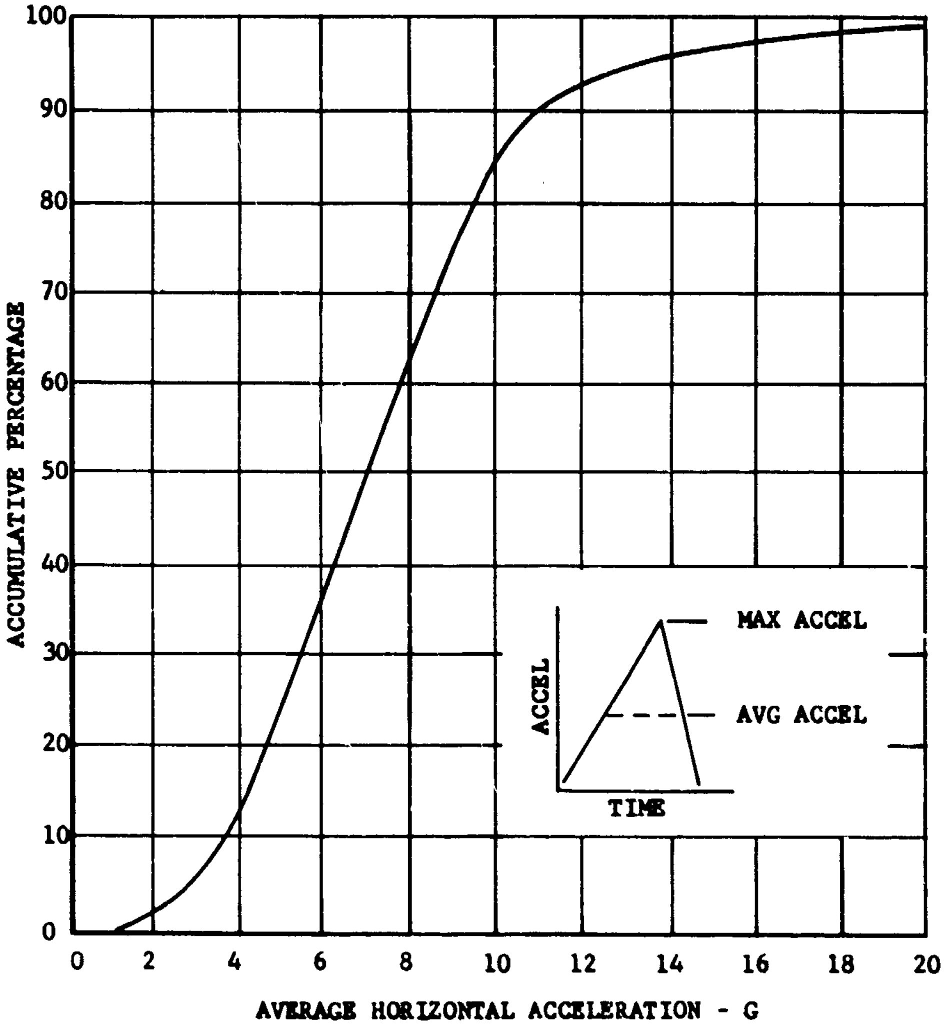

Figure 13. Distribution of Longitudinal Impact Forces - Fixed-Wing Transport Aircraft.

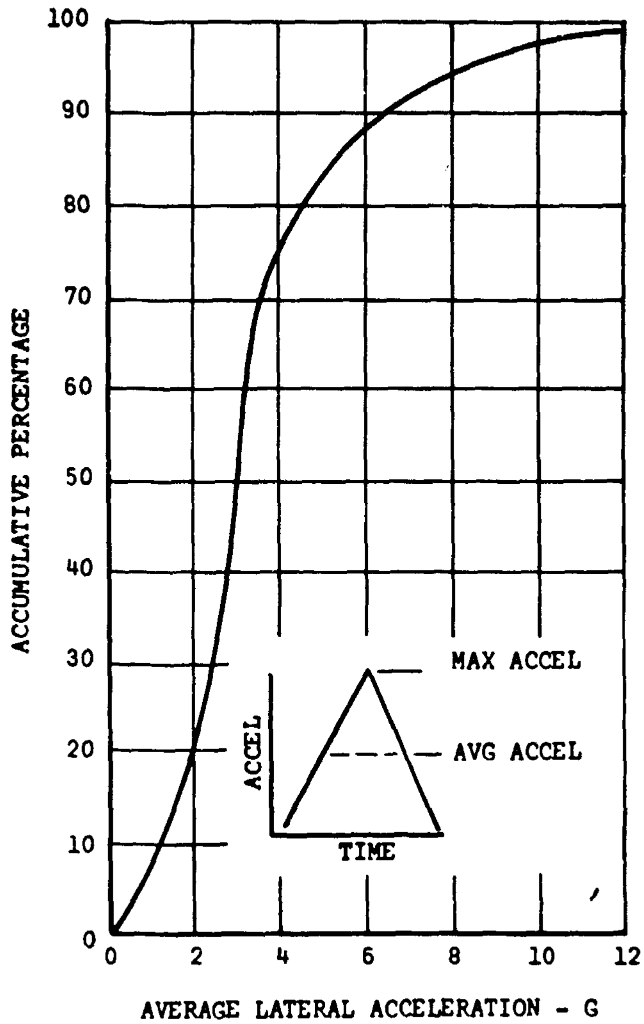

Figure 14. Distribution of Lateral Impact Forces - Fixed-Wing Transport Aircraft.

TABLE III

CIVIL TRANSPORT ACCIDENTS IN WHICH SURVIVAL COULD HAVE BEEN INCREASED WITH IMPROVED PROTECTION (IMPACT ANGLE 0 TO 5 DEGREES)

REF NO.	AVG HORIZ G FORCE	AVG VERT G FORCE	AVG LAT G FORCE	NO. OF FUSE. BREAKS	MAJOR VEL CHANGE (FPS)	TOTAL PERSONS ABOARD	TOTAL FATAL-ITIES	TOTAL FATAL-ITIES DUE TO FIRE	TOTAL SUR-VIVORS	SUR-VIVORS WITHOUT SERIOUS INJURY	POTENTIAL ADDED SURVIVORS WITHOUT SERIOUS INJURY	REMARKS
3	4-6	1-2	2-3	1	35-45	74	28	none	46	46	10-20	Unsurvivable over fuse-lage fracture point.
4	13	2	-	1	35-45	17	17	none	none	none	1-5	Tail section only sur-vivable.
5	4	1-2	2-3	0	20-30	23	none	none	23	22	1	Serious injury due to one seat failure.
7	6-8	8-12	2-4	unk	50-70	22	15	unk	7	4	unk	
10	3-6	3-6	2-3	unk	20-30	3	2	none	1	none	1	
15	5-6	2-3	2-3	0	20-30	62	none	none	62	43	10-19	Injuries due to seat failure.
16	4-6	3-5	0.5-1	1	20-30	28	3	none	25	21	1	
17	8-10	3-6	1-2	2	80-100	73	65	none	8	none	15-20	Water impact; many passen-gers drowned.
18	1-2	2-3	-	0	20-30	2	none	none	2	2	0	
22	6-8	0.5-1	2-3	0	30-50	94	80	80	14	4	20-40	Majority of seats failed.
23	6	0.5-1	6	1	30-50	48	22	14	26	16	24-30	Majority of survivors were thrown out of wreck-age.

TABLE III - CONTINUED

REF NO.	AVG HORIZ G FORCE	AVG VERT G FORCE	AVG LAT G FORCE	NO. OF FUSE. BREAKS	MAJOR VEL CHANGE (FPS)	TOTAL PERSONS ABOARD	TOTAL FATAL-ITIES	TOTAL FATAL-ITIES DUE TO FIRE	TOTAL SUR-VIVORS	SUR-VIVORS WITHOUT SERIOUS INJURY	POTENTIAL ADDED SURVIVORS WITHOUT SERIOUS INJURY	REMARKS
25	2-3	1-2	1-2	0	25-30	2	none	none	2	1	unk	
27	2-3	2-3	0.5-1.5	0	20-30	7	1	1	6	6	1	Crewmember was trapped.
28	8-12	2-3	6-8	1	40-60	40	27	13	13	7	15-25	Cockpit area unsurvivable.
29	5-10	5-10	1-3	0	60-80	76	28	none	48	48	10-20	Several seat failures.
30	6-8	4-6	2-4	2	30-50	51	25	20	26	12	34-39	Unsurvivable in break areas.
31	4-6	1-2	2-3	1	40-60	42	none	none	42	41	1	
35	5-7	2-4	2-3	1	25-35	2	none	none	2	none	unk	
36	6-10	4-8	3-5	2	50-65	43	7	none	36	6	20-30	
37	2-4	4-6	2-4	1	25-30	2	1	none	1	none	1	Copilot crushed by structure.
38	3-5	4-6	0.5-1	unk	30-40	15	none	none	15	13	unk	
40	2-4	1-3	0-1	0	30-40	30	1	none	29	28	1	Both cockpit seats failed.

TABLE IV

CIVIL TRANSPORT ACCIDENTS IN WHICH SURVIVAL COULD HAVE BEEN INCREASED WITH IMPROVED PROTECTION (IMPACT ANGLE 5 TO 10 DEGREES)

REF NO.	AVG HORIZ G FORCE	AVG VERT G FORCE	AVG LAT G FORCE	NO. OF FUSE. BREAKS	MAJOR VEL CHANGE (FPS)	TOTAL PERSONS ABOARD	TOTAL FATAL-ITIES	TOTAL FATAL-ITIES DUE TO FIRE	TOTAL SUR-VIVORS	SUR-VIVORS WITHOUT SERIOUS INJURY	POTENTIAL ADDED SURVIVORS WITHOUT SERIOUS INJURIES	REMARKS
1	6-8	10-12	1-2	1	50-70	35	13	none	22	1	15-25	Floor breakup caused seat failure.
2	6-9	3-5	2-4	1	60-80	43	22	none	21	9	unk	No information on fatalities.
6	6-10	2-3	4-6	2	50-65	36	22	none	14	7	unk	No information on fatalities.
8	6-8	10-15	1-2	0	50-70	10	1	none	9	4	5	
9	3-6	3-6	2-3	0	30-50	101	20	20	81	53	20-40	Fatalities due to fire only.
11	6-10	2-4	4-8	2	40-50	24	12	none	12	0	2-5	Extensive floor breakup.
12	6-10	4-6	2-3	3	45-75	24	9	none	15	5	4-8	Four fatalities in forward section; 5 in center section.
13	10-12	2-3	6-10	0	25-40	3	1	1	2	0	1	
21	4-6	2-3	2-3	0	20-40	19	1	none	18	16	1	Cartwheel; copilot thrown free.
26	3-6	less than 6	0	0	60-100	79	77	77	2	2	0	All fatalities due to CO poisoning. Door exits jammed.
43	10-20	5-10	4-6	unk	30-50	4	4	none	0	0	0	

TABLE V

CIVIL TRANSPORT ACCIDENTS IN WHICH SURVIVAL COULD HAVE BEEN INCREASED WITH IMPROVED PROTECTION (IMPACT ANGLE 10 DEGREES AND HIGHER)

REF NO.	AVG HORIZ G FORCE	AVG VERT G FORCE	AVG LAT G FORCE	NO. OF FUSE BREAKS	MAJOR VEL CHANGE (FPS)	TOTAL PERSONS ABOARD	TOTAL FATAL-ITIES	FATAL-ITIES DUE TO FIRE	TOTAL SUR-VIVORS	SUR-VIVORS WITHOUT SERIOUS INJURY	POTENTIAL ADDED SURVIVORS WITHOUT SERIOUS INJURY	REMARKS
14	15-25	5	5-10	2	50-80	34	25	10	9	0	10-15	Unsurvivable in cockpit.
19	6-10	18	1-2	1	50-80	2	none	none	2	1	1	
20	6-10	6-8	4-8	1	40-60	8	4	none	4	3	1	
24	10-20	1-2	1-2	2	60-100	72	62	none	10	0	12-16	Unsurvivable in cockpit. Survivable in tail section.
32	8-10	5-8	1-2	1	40-60	3	3	none	0	0	0	Crew survived but died of exposure in water.
33	9-11	50-60	5 or less	1	70-90	8	8	none	0	0	1-2	Survivable in tail section.
34	5-10	10-14	2	0	40-60	8	4	4	4	0	4-8	
39	3-5	3-4	3-5	1	20-40	3	1	none	2	1	unk	
41	8-12	10-15	1-2	1	40-60	5	5	none	0	0	unk	
42	5-7	5-7	none	1	40-50	145	none	none	145	130	9-12	Injury potential at fuselage break.

TABLE VI

MILITARY TRANSPORT ACCIDENTS IN WHICH SURVIVAL COULD HAVE BEEN INCREASED WITH IMPROVED RESTRAINT (IMPACT ANGLE 0 TO 5 DEGREES)

REF NO.	AVG HORIZ G FORCE	AVG VERT G FORCE	AVG LAT G FORCE	NO. OF FUSE. BREAKS	MAJOR VEL CHANGE (FPS)	TOTAL PERSONS ABOARD	TOTAL FATAL-ITIES	TOTAL FATAL-ITIES DUE TO FIRE	TOTAL SUR-VIVORS	SUR-VIVORS WITHOUT SERIOUS INJURY	POTENTIAL ADDED SURVIVORS WITHOUT SERIOUS INJURIES	REMARKS
13A	5-8	1-2	1-2	2	50-65	11	4	3	7	4	6	
4A	6-8	5-7	1-2	0	45-55	6	6	6	none	0	6	All fatalities had elevated blood CO levels.
6A	10	3	4-6	2	35-45	8	3	none	5	0	2	Cockpit demolished; 2 survivors in aft-facing seats.
8A	6-8	4-6	3-4	1	30-40	4	1	unk	3	3	unk	Unknown why fatality did not exit aircraft.
9A	4-6	2-3	0.5-1	0	20-30	4	none	none	4	4	-	
11A	4-6	3-4	2-3	4	25-35	83	78	78	5	0	40-80	All survivors on flight deck.
12A	5-7	3-5	1-2	unk	25-35	5	5	5	0	0	2-4	All found in respective positions.
14A	3-4	2-3	1-2	0	20-30	36	none	none	36	32	4	No restraint for 31 passengers.
15A	8-10	2-3	3-4	1	60-80	10	4	none	6	2	4	Passengers probably crushed or trapped by cargo.
16A	4-8	6	1-2	1	30-40	7	none	none	7	3	unk	Fuselage broke aft of cockpit and flipped on top of cockpit.
17M	5-10	6-10	2-3	2	40-50	8	6	2	2	0	2	

TABLE VII

MILITARY TRANSPORT ACCIDENTS IN WHICH SURVIVAL COULD HAVE BEEN INCREASED WITH IMPROVED RESTRAINT (IMPACT ANGLE 5 DEGREES AND HIGHER)

REF NO.	AVG HORIZ G FORCE	AVG VERT G FORCE	AVG LAT G FORCE	NO. OF FUSE. BREAKS	MAJOR VEL CHANGE (FPS)	TOTAL PERSONS ABOARD	TOTAL FATAL-ITIES	TOTAL FATAL-ITIES DUE TO FIRE	TOTAL SUR-VIVORS	SUR-VIVORS WITHOUT SERIOUS INJURY	POTENTIAL ADDED SURVIVORS WITHOUT SERIOUS INJURIES	REMARKS
3A	8-10	5	4-6	1	50-70	7	7	unk	0	0	unk	Possible survivable conditions in cabin.
5A	6	6	2-3	0	35-45	6	5	5	1	0	6	Pilot was rescued through cockpit window.
7A	7-9	10-12	2-3	2	50-70	20	1	none	19	16	3	
2A	7	10	1-2	0	30-60	8	1	1	7	6	2	Copilot unconscious; died in fire.
1A	6-8	25	1-2	0	35-45	7	none	none	7	4	3	Hard vertical impact.
10A	6-8	3-5	3-4	0	30-40	8	4	none	4	3	5	Fatalities and injured had no restraint.
18H	2-4	6-8	1-2	1	25-35	7	0	0	7	5	2	Serious injuries due to restraint failure.

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APPENDIX I

CIVIL TRANSPORT ACCIDENTS IN WHICH SURVIVAL WA

			AIRCRAFT ATTITUDE			IMPACT CONDITIONS				CREW INJURIES			PASSEN
Ref No.	Type Air-craft	Date	Pitch (Deg.)	Roll (Deg.)	Yaw (Deg.)	Vel (Kn.)	Impact Angle (Deg.)	Total Decel Dist (Ft.)	Total Aboard	Fatal	Seri-ous	Minor or None	Fatal
1	CV-240	Mar. 55	1-2D	5R	None	120	7-8	750	35	2	1	0	11
2	Convair 340	July 55	2-5D	5-7R	10-20R	120	10	900	43	2	1	0	20
3	C-54 DC	Nov. 55	10-15U	0	None	90	3.5	650	74	1	0	3	27
4	Lockh.L749	Dec. 55	Level	11R	-	140	2.5	360	17	5	0	0	[illegible]
5	Martin 404	Feb. 56	1-3U	5-10R	None	90	3-5	900	23	0	0	3	0
6	Martin 404	Apr. 56	-	35L	-	100	-	240	36	1	2	0	21
7	DC-6B	Aug. 56	-	15L	-	186	-	1500	22	4	3	1	11
8	Convair 240	Jan. 57	Level	0	0	120	7	540	10	0	2	1	1
9	DC-6A	Feb. 57	Level	19L	8L	138	[illegible]	1500	101	0	3	3	20
10	DC-4	May 57	0-2D	0	0	140-160	-	450[illegible]	3	2	1	0	-
11	DC-3	Sep. 57	30D	90R	25R	65	8	145	24	2	1	0	10
12	DC-7C	Mar. 58	0-5D	20R	0	175	7	1500	24	0	3	2	9
13	DC-3	June 58	30D	80R	-	65	-	30-50	3	1	2	0	-
14	Convair 240	Aug. 58	17D	180	-	130	13	1100	34	3	0	0	22
15	DC-6B	Aug. 58	Level	-	0	155	1-2	1300	62	0	1	3	0
16	DC-3	Feb. 59	Level	10L	-	70	5	208	28	2	1	0	1
17	Electra	Feb. 59	Level	2-3R	0	135	2-3	-	73	2	3	0	63
18	Convair 240	Mar. 59	Level	2R	-	120	2.5	500	2	0	0	2	-
19	C-54G	Oct. 59	Level	2-3L	-	75	25	360	2	0	1	1	-
20	Boeing 707	Oct. 59	10-15D	55L	5-15L	-	12	350	8	3	0	0	1
21	DC-3	Oct. 59	20-30D	8-12L	-	70	-	80-100	19	1	1	1	0
22	DC-6AB	Sep. 60	10U	5R	0	150	9	975	94	7	1	0	73
23	C-46F	Oct. 60	-	60-90L	-	90	2-5	215	48	2	0	1	20
24	Electra II	Oct. 60	70-75D	80-85L	-	100	60-80	40-70(d)	72	3	2	0	59
25	C-46	July 61	Level	2L	0	70-80	6	1000	2	0	1	1	-
26	Lockh. 049E	Nov. 61	Level	10R	0	90-95	8-10	100	79	3	0	2	74
27	Lockh. 1049H	Mar. 62	Level	-	-	120	2-3	2000	7	1	0	6	-
28	Britannia 314	July 62	2-3D	10-20L	-	115	1-2	680	40	7	4	0	20
29	Lockh. 1049H	Sep. 62	Level	0	-	100	2-3	-	76	5	0	3	23
30	DC-7B	Nov. 62	5	6L	0	134	2	900	51	4	2	0	21
31	Convair 340	Dec. 62	Level	2-5L	6R	115	5	1275	42	0	1	2	0
32	F-27	Jan. 63	Level	0	0	110	11	-	3	3(a)	0	0	-
33	Viscount 812	Jan. 63	22D	0	0	150	30	600	8	3	0	0	5
34	Lockh. 1049H	Feb. 63	5D	5L	-	100	12.5	800	8	2	1	0	2
35	C-46F	Feb. 63	20D	30L	-	80-90	-	219	2	0	2	0	-
36	Martin 404	July 63	35D(b)	90-135L	20-30L	90-95	1	175	43	2	1	0	5
37	C-46	Aug. 63	3-5U	0	0	80	1-2	750	2	1	1	0	-
38	F-27	Aug. 63	Level	0	0	88	5	800	15	0	0	3	0
39	DC-3	Nov. 63	-	-	-	100	10	550	3	1	1	1	-
40	DC-3A	Mar. 64	Level	0	0	70-80	1-2	120	30	1	1	0	0
41	DC-3C	Mar. 64	4U	6L	-	100	20	610(c)	5	3	0	0	2
42	Boeing 707	Apr. 64	1-2D	0	1-2R	20-30	35-45	2-4	145	0	1	8	0
43	C-46	Dec. 64	Level	18C	-	110	8	850	4	2	0	0	2

a. Crew survived crash, exited the aircraft, and died due to freezing water exposure.
b. Aircraft shredded left wing over 163 feet before nose impacted ground (35-degree pitch was main impact
c. Aircraft bounced off the top of two hills and came to rest on third hill. The 610 feet includes 300 f
d. This estimated distance based on water depth and forward fuselage deformation.

APPENDIX I

TS IN WHICH SURVIVAL WAS POSSIBLE (42 CASES)

	CREW INJURIES			PASSENGER INJURIES				
Total Aboard	Fatal	Serious	Minor or None	Fatal	Serious	Minor or None	Post-crash Fire	Terrain Conditions
35	2	1	0	11	20	1	No	Plowed field.
43	2	1	0	20	11	9	Minor	Grass field with obstacles.
74	1	0	3	27	0	43	Yes	Residential street - pavement.
17	5	0	0	12	0	0	Yes	Packed earth.
23	0	0	3	0	1	19	No	Grass covered ground.
36	1	2	0	21	5	7	Yes	Firm ground.
22	4	3	1	11	0	3	Yes	Unknown.
10	0	2	1	1	3	3	No	Unknown.
101	0	3	3	20	25	50	Yes	Hard frozen earth.
3	2	1	0	-	-	-	Yes	Icecap.
24	2	1	0	10	11	0	Minor	Forest.
24	0	3	2	9	7	3	Yes	Swamp with jagged rock.
3	1	2	0	-	-	-	Yes	Soft sandy ground.
34	3	0	0	22	9	0	Yes	Soft forest ground.
62	0	1	3	0	18	40	Yes	Unknown.
28	2	1	0	1	3	21	Yes	Firm forest ground.
73	2	3	0	63	5	0	No	Water (unintentional).
2	0	0	2	-	-	-	Yes	Hard ground (railroad yard).
2	0	1	1	-	-	-	Yes	Edge of lake.
8	3	0	0	1	1	3	Yes	Along river edge.
19	1	1	1	0	1	15	No	Hard ground.
94	7	1	0	73	9	4	Yes	Jungle - low vegetation.
48	2	0	1	20	10	15	Yes	Hard packed ground.
d) 72	3	2	0	59	8	0	No	Stalled and fell into shallow water.
2	0	1	1	-	-	-	No	Runway.
79	3	0	2	74	0	0	Yes	Dense woods.
7	1	0	6	-	-	-	Yes	Earth embankment (gear).
40	7	4	0	20	2	7	Yes	Hard ground.
76	5	0	3	23	0	45	No	Water (intentional).
51	4	2	0	21	12	12	Yes	Hard ground side of runway.
42	0	1	2	0	0	40	Yes	Hard frozen ground.
3	3(a)	0	0	-	-	-	No	Water (unintentional).
8	3	0	0	5	0	0	Yes	Packed earth.
8	2	1	0	2	3	0	Yes	Concrete runway.
2	0	2	0	-	-	-	Yes	Meadow.
43	2	1	0	5	29	6	Minor	Edge of runway, grassy sod, in driving rain.
2	1	1	0	-	-	-	No	Plowed field.
15	0	0	3	0	2	10	Unk	Unknown.
3	1	1	1	-	-	-	No	Dense woods.
30	1	1	0	0	0	28	No	Unknown.
5	3	0	0	2	0	0	Yes	Hard ground.
145	0	1	8	0	14	122	No	Shallow water-embankment.
4	2	0	0	2	0	0	No	Farmland.

ater exposure.
d (35-degree pitch was main impact).
hill. The 610 feet includes 300 feet of airborne distance.
formation.

APPENDIX II

MILITARY TRANSPORT ACCIDENTS IN WHICH SURVIVAL WA

			AIRCRAFT ATTITUDE			IMPACT CONDITIONS				CREW INJURIES			PASSENGER I	
Ref No.	Type Air-craft	Date	Pitch (Deg.)	Roll (Deg.)	Yaw (Deg.)	Velocity (Kn.)	Impact Angle (Deg.)	Total Decel Dist (Ft.)	Total Aboard	Fatal	Seri-ous	Minor or None	Fatal	Seri-ous
1A	C-47D	1962	30up	0	0	80	30	348	7	0	0	2	0	3
2A	C-47D	1962	20-30up	0	0	90-105	10-20	-	8	1*	1	2	0	0
3A	C-47A	1962	5-10up	60L	-	60-70	5-10	200	7	3	0	0	4	0
4A	KC-135A	1962	5-10up	20L	9L	170-180	5	1000	6	6*	0	0	-	-
5A	C-140	1962	2-3up	2-3R	0	175	10-15	1000	6	2*	1	0	3*	0
6A	C-121G	1962	Level	0	0	120	3-5	1900	8	3	5	0	-	-
7A	C-131E	1963	10-15up	20R	2-5R	123	12-15	300	20	1	1	2	0	2
8A	KC-135A	1963	-	0	-	130-150	2-5	150	4	1	0	3	-	-
9A	C-47D	1963	Level	0	0	100-120	1-2	393	4	0	0	4	-	-
10A	C-123B	1964	2-5d	0	2-4L	70	10-15	300	8	4	1	3	-	-
11A	C-135B	1964	2-4up	2-3L	0	150	2-3	1640	83	5*	5	0	73*	0
12A	KC-97G	1964	2-5d	10R	-	120	2-5	1400	5	5*	0	0	-	-
13A	KC-97G	1964	5-10up	0	0	105	20-30	200	11	0	1	3	4	2
14A	VC-47D	1965	2-5up	-	-	70	2-3	350-400	36	0	0	5	0	4
15A	C-130A	1965	Level	1-5L	1-3R	130	1-3	Water	10	2	1	2	2	3
16A	C-123B	1965	Level	0	0	100	2-5	250	7	0	2	2	0	2
17N	C-54Q	1964	5-10d	5R	-	130	5	380	8	5	1	0	1	1
18N	EC-121K	1963	Level	0	10L	15-25	20-30	10-20	7	0	2	1	0	0

*All fatalities had elevated CO-levels in blood samples.

APPENDIX II

IDENTS IN WHICH SURVIVAL WAS POSSIBLE

CREW INJURIES			PASSENGER INJURIES				
Fatal	Seri-ous	Minor or None	Fatal	Seri-ous	Minor or None	Post-crash Fire	Terrain Conditions
0	0	2	0	3	2	No	Frozen earth.
1*	1	2	0	0	4	Yes	Frozen earth.
3	0	0	4	0	0	Yes	Runway and firm grassy soil.
6*	0	0	-	-	-	Yes	Heavily wooded area.
2*	1	0	3*	0	0	Yes	Hard grass covered slope.
3	5	0	-	-	-	Yes	Firm grassy soil, hilly terrain.
1	1	2	0	2	14	No	Soft earth with rocks and shrubs.
1	0	3	-	-	-	Yes	Heavily wooded hill.
0	0	4	-	-	-	No	Firm rocky soil with shrubs.
4	1	3	-	-	-	Minor	Firm soil, thin underbrush.
5*	5	0	73*	0	0	Yes	Hard grass covered soil.
5*	0	0	-	-	-	Yes	Golf course.
0	1	3	4	2	1	Yes	Soft earth, slid onto concrete runway.
0	0	5	0	4	27	Yes	Hard soil.
2	1	2	2	3	0	No	Hit water, skipped twice and sank.
0	2	2	0	2	1	No	Hard grassy soil.
5	1	0	1	1	0	Yes	Trees and hard ground.
0	2	1	0	0	4	Yes	Runway overrun into drainage ditch.

APPENDIX II
MILITARY TRANSPORT ACCIDENTS IN WHICH SURVIVAL WA

			AIRCRAFT ATTITUDE			IMPACT CONDITIONS				CREW INJURIES			PASSENGER	
Ref No.	Type Air-craft	Date	Pitch (Deg.)	Roll (Deg.)	Yaw (Deg.)	Velocity (Kn.)	Impact Angle (Deg.)	Total Decel Dist (Ft.)	Total Aboard	Fatal	Seri-ous	Minor or None	Fatal	Seri ous
1A	C-47D	1962	30up	0	0	80	30	348	7	0	0	2	0	3
2A	C-47D	1962	20-30up	0	0	90-105	10-20	-	8	1*	1	2	0	0
3A	C-47A	1962	5-10up	60L	-	60-70	5-10	200	7	3	0	0	4	0
4A	KC-135A	1962	5-10up	20L	9L	170-180	5	1000	6	6*	0	0	-	-
5A	C-140	1962	2-3up	2-3R	0	175	10-15	1000	6	2*	1	0	3*	0
6A	C-121G	1962	Level	0	0	120	3-5	1900	8	3	5	0	-	-
7A	C-131E	1963	10-15up	20R	2-5R	123	12-15	300	20	1	1	2	0	2
8A	KC-135A	1963	-	0	-	130-150	2-5	150	4	1	0	3	-	-
9A	C-47D	1963	Level	0	0	100-120	1-2	393	4	0	0	4	-	-
10A	C-123B	1964	2-5d	0	2-4L	70	10-15	300	8	4	1	3	-	-
11A	C-135B	1964	2-4up	2-3L	0	150	2-3	1640	83	5*	5	0	73*	0
12A	KC-97G	1964	2-5d	10R	-	120	2-5	1400	5	5*	0	0	-	-
13A	KC-97G	1964	5-10up	0	0	105	20-30	200	11	0	1	3	4	2
14A	VC-47D	1965	2-5up	-	-	70	2-3	350-400	36	0	0	5	0	4
15A	C-130A	1965	Level	1-5L	1-3R	130	1-3	Water	10	2	1	2	2	3
16A	C-123B	1965	Level	0	0	100	2-5	250	7	0	2	2	0	2
17N	C-54Q	1964	5-10d	5R	-	130	5	380	8	5	1	0	1	1
18N	EC-121K	1963	Level	0	10L	15-25	20-30	10-20	7	0	2	1	0	0

*All fatalities had elevated CO-levels in blood samples.

APPENDIX II

IDENTS IN WHICH SURVIVAL WAS POSSIBLE

CREW INJURIES			PASSENGER INJURIES				
Fatal	Seri-ous	Minor or None	Fatal	Seri-ous	Minor or None	Post-crash Fire	Terrain Conditions
0	0	2	0	3	2	No	Frozen earth.
1*	1	2	0	0	4	Yes	Frozen earth.
3	0	0	4	0	0	Yes	Runway and firm grassy soil.
6*	0	0	-	-	-	Yes	Heavily wooded area.
2*	1	0	3*	0	0	Yes	Hard grass covered slope.
3	5	0	-	-	-	Yes	Firm grassy soil, hilly terrain.
1	1	2	0	2	14	No	Soft earth with rocks and shrubs.
1	0	3	-	-	-	Yes	Heavily wooded hill.
0	0	4	-	-	-	No	Firm rocky soil with shrubs.
4	1	3	-	-	-	Minor	Firm soil, thin underbrush.
5*	5	0	73*	0	0	Yes	Hard grass covered soil.
5*	0	0	-	-	-	Yes	Golf course.
0	1	3	4	2	1	Yes	Soft earth, slid onto concrete runway.
0	0	5	0	4	27	Yes	Hard soil.
2	1	2	2	3	0	No	Hit water, skipped twice and sank.
0	2	2	0	2	1	No	Hard grassy soil.
5	1	0	1	1	0	Yes	Trees and hard ground.
0	2	1	0	0	4	Yes	Runway overrun into drainage ditch.

2

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13. ABSTRACT

Floor level deceleration data obtained in FAA crash tests of a DC-7 and a L-1649 transport are analyzed and compared with earlier NACA data on twin-engine transports. Generally, the comparison of the NACA and FAA data revealed that for equal impact angles and velocities, the deceleration pulses as recorded by NACA and the FAA were nearly equal. When fuselage breaks occur, deceleration values in the separated sections may exceed the deceleration level of an intact airframe. The longitudinal compressive strength of a separated fuselage section may allow as much as 19G to be imposed on the section when one-third of the cross-sectional area is effective in buckling.

A study of 61 survivable transport aircraft accidents in the years from 1955 through 1964 revealed the following significant points: (1) Floor deceleration pulse magnitudes and durations seldom exceed human tolerance limits if proper body restraint is available; (2) At least one fuselage fracture break was noted in each of 35 accidents out of a total of 61 accidents studied, and these breaks resulted in seat failures and passenger injuries in many of these cases; (3) Two-thirds of the accidents studied resulted in a postcrash fire; and (4) It is estimated that approximately one-half of the injuries and fatalities could have been prevented by the use of improved passenger restraint systems.

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